Indonesian Journal of Digital Business

Journal homepage: https://ejournal.upi.edu/index.php/IJDB/index

Economic Evaluation on the Production of Chitosan-Kaolinite Nanocomposite from Prawn Shell Waste

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A B S T R A C T

Chitosan-kaolinite clay nanocomposite is one of the nanocomposite biopolymers that can be used to remove heavy metals in wastewater treatment processes. This type of adsorbent can be modified from marine animal waste (especially shells), for example, prawn. The purpose of this study is to analyze if this adsorbent manufacturing project can be carried out or not, by taking into various perspectives including engineering and economic perspectives. Several parameters for economic evaluation have been analyzed in this paper, such as the length of time to obtain initial capital after the project is executed (PBP), the calculation of the total net profit value since the start of construction in years (CNPV), and so on. The results show that this project is prospective from an engineering and economic point of view. Characterized by the capital that is recovered after three years of the project. Marked by the increase in the Profitability Index (PI) value of 86.4230 from -0.9746 which is the second year PI value. In one day this project can produce 37.5 tons from three shifts of work. The total profit earned in one year reached 5,551,803.98 USD under ideal conditions. This project is considered to be able to compete in the market because PBP occurs in the third year of the project. Apart from the results of this economic analysis, this project is considered as a project that can be chosen as a way to utilize aquatic waste as an effort to maintain the beauty of the earth.

Keywords

Metode *Prototype,*
Quality Service,
Rancang Bangun,
Sistem Informasi

1. INTRODUCTION

Clay polymer nanocomposites have been widely used as adsorbents in the most efficient and cost-effective adsorption process for wastewater treatment (Raval et al., 2016). Polymer clay nanocomposites are designed using many combinations of clay minerals and polymers. Initially, the clay minerals are dispersed into individual layers and introduced into the polymer phase, usually less than 5% by weight, to improve polymer properties (Chen et al., 2008).

The reuse of fishery waste from industry is not a common practice, and most of the waste biomass is usually discharged directly into the environment without any treatment (Nguyen et al., 2019). Annually, the seafood industry generates about 106 tonnes of waste, most of which is used for composting or for conversion into low value-added products such as animal feed and fertilizers. (Schmitz et al., 2019). Marine animals usually contain a lot of chitin compounds that can be found in the shells of crustaceans such as crab and shrimp, for the simple reason that they are easily obtained as a waste from the seafood processing industry (Kurita, 2001).

Chitin is less soluble in water and more difficult to process, therefore chitin is usually converted to chitosan. Chitosan is known as a partially deacetylated chitin derivative. Chitosan is expected to be used in various applications such as agriculture; water and wastewater treatment; food and Drink; chemical material; feeding; cosmetics; and personal care (Zuber et., al, 2013 dan Rinaudo, 2006). In addition, chitosan has been found naturally in several types of biomass. Some fungi contain chitosan as an important constituent of their cell walls at various stages of their life cycle. The class *Zygomycetes* (e.g., the genera *Mucor, Absidia, Benjaminiella, Cunninghamella, Gongronella*, and *Rhizopus*) have been recognized as valuable sources of chitosan. (Kafetzopoulos et., al, 1993 dan Percot et., al, 2003). Chitosan content of 1-10% on a dry biomass basis has been found with a reported deacetylation rate of 83-94%.

Chitosan is not synthesized directly but is the result of efficient conversion of chitin in the presence of deacetylase enzymes (Dhillon et., al, 2013). In addition, deacetylation can be carried out in an alkaline solution using sodium or potassium hydroxide (Aranaz et., al, 2009). Most sources state a deacetylation rate of at least 50% (Rinaudo, 2006) as a criterion for defining the molecule as chitosan.

In this method, Bijoypur clay is used which is rich in kaolinite clay minerals. Consists of a high percentage of SiO_2 (70.08%), a large amount of Al_2O_3 (27.24%), and a fairly low content of impurities such as Fe_2O_3 (1.03%) and TiO_2 (1.65%) (Mousharraf et al., 2012). Unlike montmorillonite clay, kaolinite has a 1:1 structure, and there is no substitution of Si^{4+} with Al^{3+} in the tetrahedral layer and no substitution of Al^{3+} with other ions (e.g. Mg^{2+}, Zn^{2+}, Fe^{2+}, Ca^{2+}, Na^{+} or K^{+}) in the octahedral layer (Bhattacharyya dan Gupta, 2008).

The purpose of this study was to evaluate the economic feasibility of making chitosan nanocomposite biopolymer clay from seafood waste. Several economic evaluation parameters used, such as GPM, IRR, ARR, NPV, CNPV, BEP, PBP, and PI were analyzed to determine the potential production of valuable materials from fishery waste. Then, the economic parameters are tested by changing various economic conditions, such as labor, sales, raw materials, utilities, and external conditions.

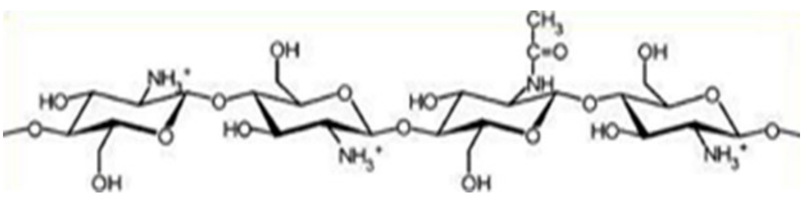

Figure 1. The structure of chitosan, adapted from Darder et al., 2003

2. Explanation of Conversion of Chitin to Chitosan

Chitin and chitosan are natural polysaccharides consisting of 2 monosaccharides, N-acetyl-D-glucosamine and D-glucosamine, linked by -1,4-glycosidic bonds. Depending on the frequency of the last monosaccharide, the molecule is defined as either chitin or chitosan. Chitin mainly contains N-acetyl-D-glucosamine and can be converted to chitosan by partial deacetylation of the monomer N-acetyl-D-glucosamine to D-glucosamine (Rinaudo, 2006). The extraction and purification of chitin and its conversion into chitosan (oligomer) require several process steps.

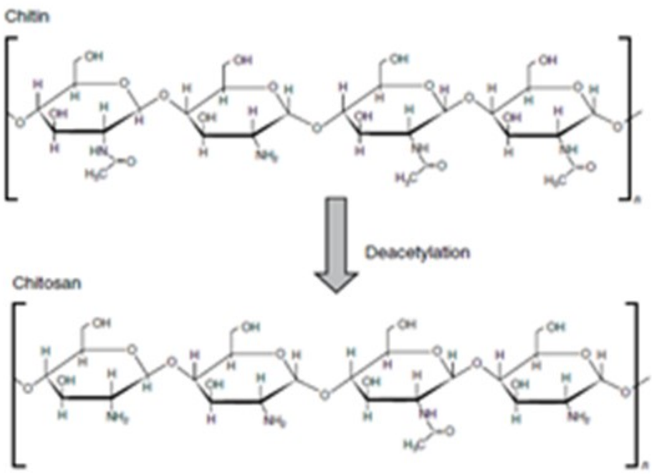

Figure 2. Differences in the structure of chitin and chitosan adapted from Rinaudo, 2006

2.1. Chitin Purification from Biomass (prawn shell)

Chitin present in biomass is closely related to other biomolecules such as proteins and minerals. These impurities need to be removed to produce high purity products for application development (Percot et., al, 2003). Generally, the process steps for isolating and purifying chitin from biomass are summarized in **Figure 3** (Bastiaens et., al, 2019).

2.1.1. Pre-treatment

is carried out to prepare the biomass and obtain pure chitin extraction. Consists of washing, cutting, boiling, and mashing processes. Prawn shell biomass goes through a pre-treatment process by washing, drying, and reducing its size (Bastiaens *et al.,* 2019).

2.1.2. Deproteination

is carried out because chitin is a chain embedded in a protein matrix and chitin can be covalently bound to proteins (Kurita, 2006; Muzarelli, 2011). Chemical deproteination is usually carried out with sodium hydroxide as the preferential reagent. The effectiveness of alkaline deproteination depends on the process temperature, alkali concentration, and alkali/biomass ratio (Al Sagheer *et al.,* 2009). For shrimp shell biomass, the NaOH concentration ranges from 0.1 to 5 M, and the temperature can increase up to 160°C. During deproteination, partial deacetylation of chitin is also common (Younes and Rinaudo, 2015).

The intensity of the demineralization and deproteination steps depends on the biomass type. It is generally accepted that these steps significantly alter the physicochemical properties of chitin, for example, molecular weight and degree of acetylation (Kaur and Dhillon, 2015). Most researchers prefer to demineralize first, followed by deproteination (Tolaimate *et al.,* 2003). However, it is considered that the order of these two phases is interchangeable depending on the biomass type (Synowiecki and Al-Khateeb, 2003).

Figure 3. Steps in the process of isolation and purification of chitin from biomass adapted from Bastiaens *et al.,* 2019

2.1.3. Demineralization

is carried out when the biomass has a high amount of minerals. For example, crustaceans can contain more than 50% (w/w) $CaCO_3$ to increase their strength (Kaya *et al.,* 2016). Two types of demineralization, there is chemical and biological demineralization. Chemical demineralization is mostly carried out using acids, but HCl is the most common reagent used to remove minerals (Kaur and Dhillon, 2015). Biological demineralization is based on an acid-producing biological process using bacteria or enzymes such as Alcalase (Kaur and Dhillon, 2015).

2.1.4. Decolorization and Post-treatment

are performed to remove pigments (such as the pink color for crustaceans), usually by adding a mild oxidizing reagent with, for example, hydrogen peroxide (Tolaimate *et al.,* 2003) or potassium permanganate (Waśko *et al.,* 2016), or extraction with solvents such as acetone (Mohammed *et al.,* 2013), ethanol, and chloroform (Kaya *et al.,* 2016). Post-treatment processes such as neutralization, washing, drying, and milling may be required to complete the chitin production process.

2.2. Conversion of Chitin to Chitosan

Chitosan production can be achieved through two approaches shown in **Figure 4.** The most common approach is to convert the extracted and purified chitin into chitosan through a deacetylation step which may be associated with several pre-treatment steps (to reduce crystallinity) and post-treatment (Bastiaens *et al.*, 2019).

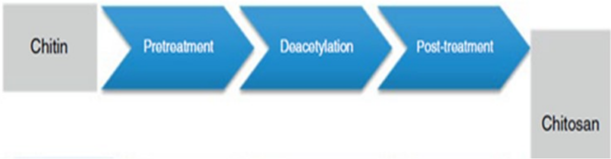

Figure 4. Stages in the process of converting chitin into chitosan adapted from Bastiaens et al., 2019

2.2.1. Deacetylation

2.2.1.1. Deacetylation Reaction Mechanism

Deacetylation is a two-step nucleophilic substitution reaction (Fig. 5). The first step consists of the nucleophilic addition of the hydroxide to the carboxyl group (Tolaimate et al., 2003), whereas, in the second step, an amine is formed (=chitosan) when the acetic acid is separated. The reaction follows pseudo-first-order kinetics during the initial period (first hour) when the base concentration is high (Galed et al., 2005).

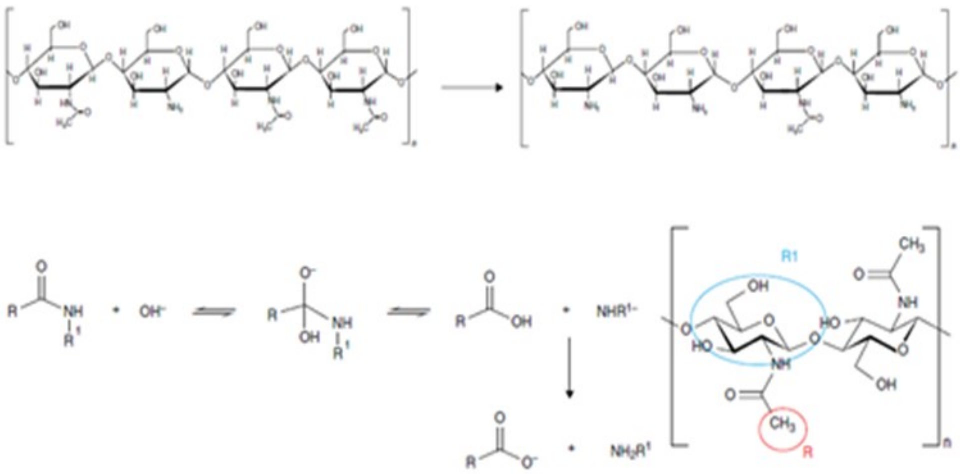

Figure 5. Deacetylation reaction mechanism adapted from Galed et al., 2005

2.2.1.2. Chemical Deacetylation Process

Deacetylation is mostly carried out in an alkaline solution using sodium or potassium hydroxide at a concentration of 30-50 %w/w (Aranaz et al., 2009). A two-stage homogeneous deacetylation process can be carried out with water-soluble chitin, referring to chitin with a degree of deacetylation (DDA) between 45% and 55% water-soluble neutral (Kurita, 2001). Heterogeneous deacetylation can be carried out in a one-step process with solid chitin. Heterogeneous deacetylation is usually carried out at higher aqueous alkali concentrations (40-50% (w/v)) and higher temperatures (100-60 °C) and is preferably for industrial use (Kaur and Dhillon, 2015).

2.2.2. Post-treatment

In the last step, the chitosan solution that has been produced usually goes through a washing step, first washed with water to neutral pH, washing with methanol, washing with acetone, and drying at 50°C for 12 hours (Tolaimate et al., 2003).

3. METHOD

The method used in this research is the method of economic feasibility analysis which is calculated using a simple mathematical analysis. The method is carried out using the following assumptions:

1. All analysis is in USD (1 USD = 14,377.73 IDR).
2. The project does not run with a loan from the bank.
3. Prices for all raw materials are based on prices available in online stores (Bukalapak, Alibaba, Tokopedia, etc.).
4. All materials used in the production process are calculated based on stoichiometric calculations.
5. The water source is free of charge because the project is located near a river.
6. The total investment cost (TIC) is calculated based on the Lang Factor (Nandiyanto, 2018).

7. Land purchased. Therefore, the land is calculated as the initial cost of building the plant and is recovered at the end of the project.
8. One cycle of making chitosan-kaolinite nanocomposite takes 8 hours.
9. In a one-day process, the estimated total processing cycle is 3 cycles, by applying 3 divisions of shift schedules to 15 people (1 shift consists of 5 people) assuming all tools work for continuous production based on time considerations. Chitosan-kaolinite nanocomposite produced 37.5 tons per day.
10. The chitosan-kaolinite nanocomposite sells for 30 USD / 20 kg.
11. Shipping costs are borne by the buyer.
12. Project one year is 264 days (remaining days are used to clean and repair tools).
13. To simplify utility, utility units are described as electrical units such as kWh. Then, the unit of electricity is considered as a cost. Assuming a utility cost of 0.07 USD/kWh.
14. Total wages/labor is assumed to be fixed at 208.65 USD/day for 15 workers.
15. The discount rate and the annual income tax rate are 10% per year, respectively.
16. The duration of the project operation is 20 years.

Several parameters for evaluating the economic feasibility as reported by Garrett (1989) are described as follows:

1) Gross Profit Margin (GPM)

An analysis is estimated by subtracting the cost of products sold from the cost of raw materials.

2) Break-Even Point (BEP)

The minimum number of products that must be sold at a certain price to cover the total cost of production.

3) Average Rate of Return (ARR)

Total inflows over the life of the investment are divided by the number of years in the life of the investment. This value is important to use to predict the state of the project.

4) Net Present Value (NPV)

The value obtained from a project stating expenses and income and using discount rate considerations.

5) Cumulative Net Present Value (CNPV)

Calculation of the total NPV value from the beginning of plant construction to the end of plant operations which can be obtained as the sum of the cumulative financial flows each year.

6) Internal Rate of Return (IRR)

IRR is a percentage that describes the average interest profit per year from all expenses and income with the same amount.

7) Profitability Index (PI)

An index is used to identify the relationship between project costs and impacts. PI calculation:

$$PI = \frac{CNPV}{TIC}$$

8) Payback Period (PBP)

PBP is a calculation carried out to predict the length of time required for an investment to be able to return the total initial expenditure. PBP is calculated based on when the CNPV first reaches zero.

4. RESULT AND DISCUSSION

4.1. Engineering Perspective

The manufacture of chitosan-kaolinite clay nanocomposite is shown in Figure 6. The mechanism used is to prepare shrimp shell samples to take chitin compounds which will be converted into chitosan. Pretreatment, deproteination, demineralization, and deacylation processes are carried out as carried out by Biswas et al., 2018. Other reactors also prepare modified clay by filtering kaolinite clay to a size of 150 mesh, then adding concentrated HCl to remove silica and other impurities. The solution is added with dodecylamine to increase the interaction of clay with chitosan and then used in the production of nanocomposites as modified clay (Yano et al., 1993). The nanocomposite was made by mixing a solution of chitosan and a modified kaolinite clay solution in an acid solution (1% acetic acid) at a temperature of 60^{o}C and then homogenized for 4 hours. The mixture is converted into beads then filtered and put in an oven at 60^{o}C for 48 hours (Wang et al., 2005).

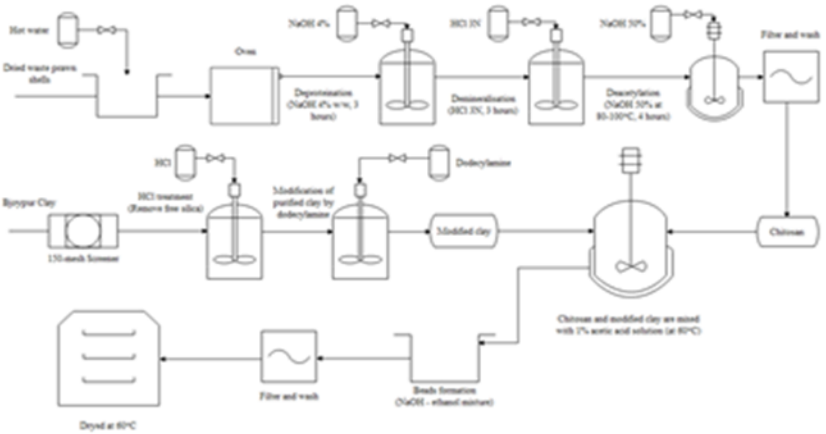

Figure 6. Process flow diagram for the synthesis of chitosan-kaolinite nanocomposite

From an engineering perspective, the total cost used to purchase raw materials for one year is 434.71 USD. Total annual sales are 14,850,000 USD with an annual profit of 5,551,803.98 USD. The cost analysis of the equipment required is 35,126.12 USD and the TIC must be less than 37,584.95 USD. This project requires a relatively low investment cost with a project life of 20 years to produce chitosan-kaolinite nanocomposites with CNPV/TIC reaching 614.93% in year 20 and PBP achieved in the third year.

4.2. Economic Evaluation

4.2.1. Ideal Condition

Figure 7 shows a graph of the relationship between lifetime (in years) on the x-axis and the value of CPNV/TIC on the y-axis over a period of 20 years. The graph shows that there is a negative value in the first two years of the project due to the cost of capital for product manufacture. The lowest CPNV/TIC value was achieved in the second year with a value of -0.9746. However, there was a sharp increase in the value of CPNV/TIC in the third year, with a value that shot up to 83.4620. In the first and second years of the project, this project did not make a profit because, in the first two years, the project cost a lot of money to buy the equipment and materials that were needed to make the product. However, in the third year, the factory received a payback period (PBP) with a significant surge in profits for the first year the factory was run. In 20

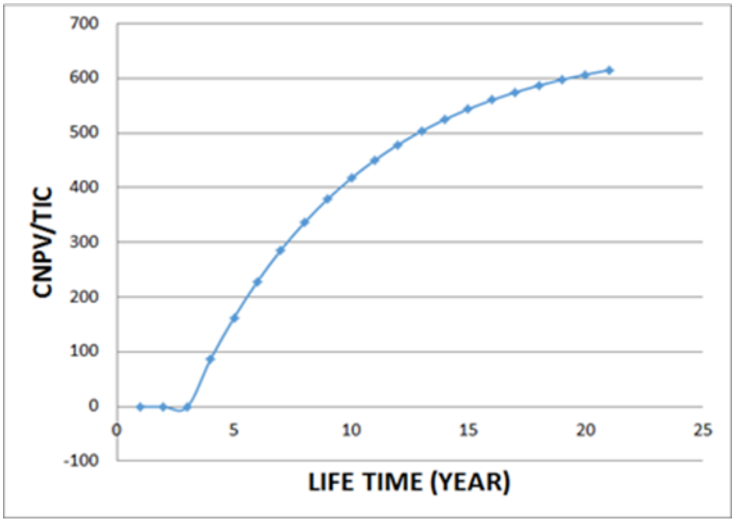

Figure 7. Graph of the relationship between CNPV/TIC values over a period of 20 years under ideal conditions

Table 1. Annual CNPV values under ideal conditions

CNPV/TIC	Tahun
0	0
-0.5916	1
-0.9746	2
86.4230	3
162.4209	4
228.5060	5
285.9714	6
335.9412	7
379.3933	8
417.1777	9
450.0337	10
478.6041	11
503.4480	12
525.0513	13
543.8368	14
560.1721	15
574.3766	16
586.7284	17
597.4691	18
606.8088	19
614.9303	20

4.2.2. The Effect of External Condition

An economic evaluation of external factors can be one of the effects of project success. One of the factors is the project taxes to fund various public expenditures. Figure 8 shows a 20-year CNPV graph with various tax changes, where the y-axis is CNPV/ TIC and the x-axis is age (years).

The initial conditions of one to three years show the same results because CNPV is under tax changes and the presence of project development. In addition, there was no income that year. The tax increase occurs after two years and will affect the CNPV value. When tax costs are added to the project, it will result in lower project profits. This is related to PBP, because the higher the tax issued, the PBP for initial capital participation will be longer than ideal.

According to PBP analysis, funds that will return when they have to pay 10%, 25%, 50%, 75%, and 100% taxes will be realized in the third year, this means that this business is feasible because when the project reaches the payback period (PBP), project profits will continue to increase into the 20th year. CNPV/TIC values in the 20th year of 10%, 25%, 50%, 75%, and 100% are 231.12; 577.8; 1155.61; 1733.41 and 2311.21%. Therefore, the highest point for obtaining BEP or project profit/loss is 100%.

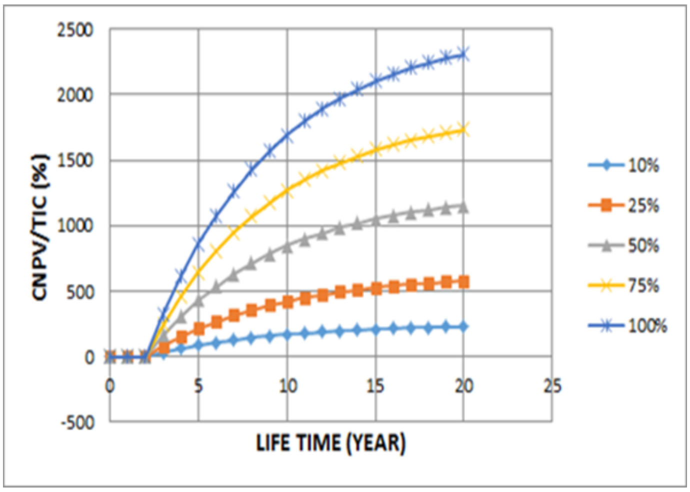

Figure 8. Graph of the relationship between the value of CPNV/TIC over a period of 20 years and various tax changes

4.2.3. Change in Sales

The analysis was carried out by increasing and decreasing sales by 10% and 20%. The ideal sales are 100% when sales are decreased by 10% and 20%, the sales are 90% and 80%, but when sales are increased by 10% and 20%, the sales will be 110% and 120%. The results of the PBP are shown in **Figure 9.** The project in its initial condition, from 0 to 2 years with various variations, shows the same CNPV/TIC value, this is because the project is still under construction and development. The greater the sales value, the more profits will increase from the project being worked on.

However, if there are conditions that cause a decrease in product sales, the project's profits will fall from the ideal state.

Profits continue to increase after reaching the Payback Period (PBP) until the 20th year. From the PBP analysis, the funds will return on the 3rd year sales in each sales variation. The profit margin generated for each year increases with increasing sales from ideal conditions. The value of CNPV/TIC in the 20th year for each variation of 80, 90, 100, 110, and 120% is 308.46; 461.70; 614.93; 768.16; and 921.40. So, sales will still generate profits if there are sales of more than 100% or less than 100% because it can be seen in the graph that it still shows a positive CNPV/TIC value.

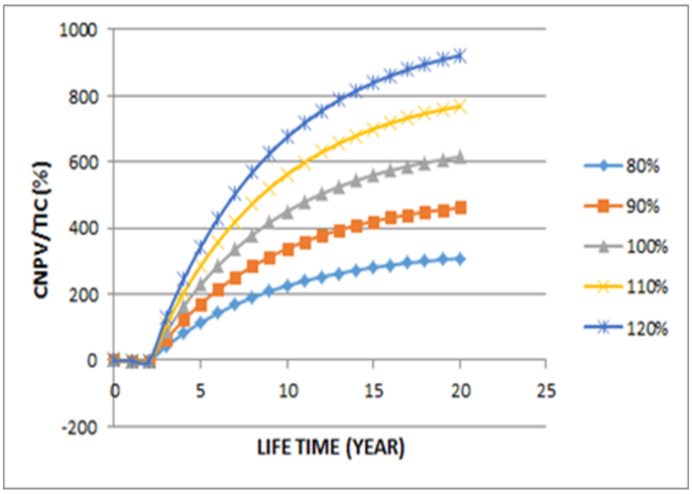

Figure 9. Graph of the relationship between the value of CNPV/TIC over a period of 20 years and various changes in

4.2.4. Change in Variable Cost (raw material, labor, utility)

Several other factors such as raw materials, utilities (electricity needs), and labor can affect the success of a project. **Figure 10** shows a CNPV/TIC value curve with varying raw material prices. The ideal conditions for the price of raw materials are shown on the 100% curve. This analysis can be done by increasing or decreasing the price of raw materials by 10-20% from the initial price. The price variations used in this analysis are 80%, 90%, 100%, 110%, and 120%.

All types of variations show a similar trend. In the first two years, the project didn't get the profit because the project is still in the development process. However, in the third year, there is a payback period in which the project has recovered the invested capital. The graph shows that the lower price of raw materials, so high profits can be earned.

The value of CNPV/TIC in the 20th year for variations in raw material prices 80%, 90%, 100%, 110%, and 120% respectively was 795.81; 705.37; 614.93; 524.49; and 434.05. This value proves that the lower the price of raw materials, the higher the income generated.

The next factor is utility. Utilities are a crucial additional requirement because it includes electricity needs during the project.

The analysis is done by increasing and decreasing the price by 10%. The ideal sale is 100%, when sales are decreased by 10% and 20%, the sales are 90% and 80%, but when sales are increased by 10% and 20%, the sales will be 110% and 120%. The results of the PBP are shown in **Figure 11**. The project in its initial condition, which is from 0 to 2 years with various variations, shows the same CNPV/TIC value because the project is still under construction and development. The effect of utility prices on the value of CNPV/TIC can be seen after 2 years after the project is created. The results of the analysis show that the variation in utility prices has no significant effect on the CNPV/TIC value, it means that the project can still run and generate profits. The value of CNPV/TIC in the 20th year on the variation of utility prices 80%, 90%, 100%, 110%, and 120% is 615.18; 615.16; 614.93; 614.80 and 614.67%. The closest PBP is achieved in the 2nd year with the biggest profit of 615.18% can be obtained from the 80% utility variation.

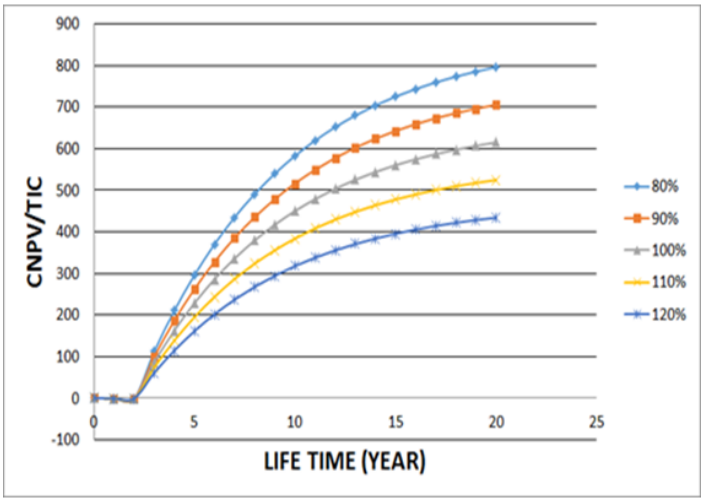

Figure 10. Graph of the relationship between the value of CNPV/TIC over a period of 20 years and various changes in

Furthermore, the CNPV/TIC graph is analyzed with various worker's salaries **(Figure 12)**, and the analysis is carried out by reducing and increasing the worker's salaries by 10% and 20% from ideal conditions. The ideal worker's salary is 100%. The coefficients used in the analysis of changes in workers' salary workers salary are 80, 90, 100, 110, and 120%. In the initial conditions of the project (0-3 years), the value of CNPV/TIC is constant. These are acquired during the project development phase. Changes in workers' salaries will affect the CPNV/TIC graph in the third year after the project is created. If the workers' salary is increased, the project's profit can be decreased. Changes in workers' salary of 80, 90, 100, 110 and 120%, the PBP results achieved are all around 3.5 years. The biggest profit is 616.67% that is obtained from the 80% worker's salary variation.

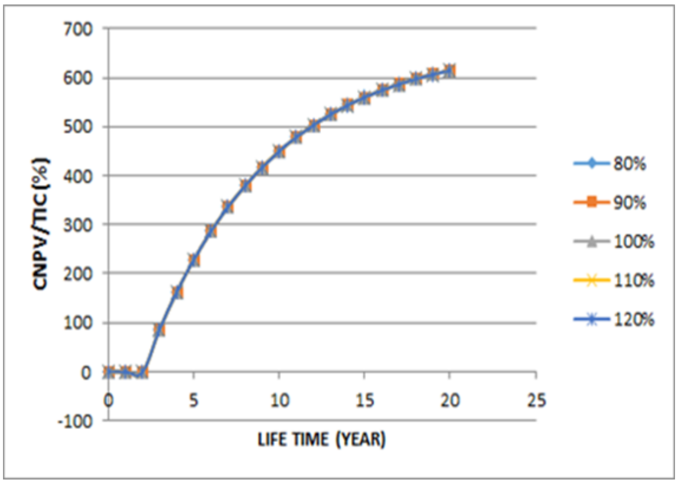

Figure 11. Graph of the relationship between the value of CNPV/TIC over a period of 20 years and various changes in utility prices

5. CONCLUSION

Based on the analysis that has been carried out and described above, the project to make chitosan-kaolinite nanocomposites using raw material of shrimp shell waste mixed with modified kaolinite is prospective from an engineering perspective and promising in its economic evaluation. PBP analysis shows that profits can be made in the third year of the project, and profits will increase rapidly after that. This project is considered to be competitive in the market because PBP was experienced in the early years of the project. Apart from the results of this economic analysis, this project is considered as a project that can be chosen as a way to utilize waste from the water sector. From the results of the economic evaluation analysis that has been carried out, it can be concluded that this project is possible to run.

6. ACKNOWLEDGEMENT

We would like to thank Bangdos, Universitas Pendidikan Indonesia.

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